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ALL-IN-ONE ABOUT A MOMENTOUS REVIEW STUDY ON COCONUT SHELL AS COARSE AGGREGATE IN CONCRETE

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ABSTRACT

Many researchers are taking their efforts to replace all the traditional constituents used for the concrete productions such as cement, fine and coarse aggregate and even for eater. Because of these many special concretes are coming out to meet out the special requirements in special situations in the construction industries. Almost one decade back, it was started by many researchers to use coconut shell as coarse aggregate in place of conventional coarse aggregate for the concrete production. They all reported encouraged results on their respective parameters studies. Authors are aimed to group the findings of coconut shell concrete under one place. Hence, happened and presented all in-one about a momentous review study on coconut shell as coarse aggregate in concrete for the benefit of Civil Engineering communities.

Key words: Review; Coconut shell; Aggregate; Concrete; Properties; Practice.

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1. INTRODUCTION

Concrete is the commonly used number one structural material in the world today. The demand to make the concrete lighter has been the theme of study that testing the scientists and engineers. The challenge in making a lightweight concrete (LWC) is decreasing the density while maintaining strength and without adversely affecting cost. Introducing novel aggregates into the mix design is a familiar way to lower a concrete's density. The crushed stone and sand are the gears that are by and large replaced with lightweight aggregate (LWA). LWC is usually made by adding natural or synthetic LWA or by entraining air into a concrete mixture. Some of the LWA used for LWC productions are pumice, perlite, expanded clay or vermiculite, coal slag, sintered fly ash, rice husk, straw, sawdust, cork granules, wheat husk, oil palm shell, palm kernel shell and coconut shell [1-3].

LWC has been used as building material for many decades throughout the world. The application ranges from lightweight partitions, walls and secondary structural components to

the primary structural components. The compressive strength ranges from 7 N/mm^2 for light partition to about 40 N/mm^2 for the primary structural components. These concretes are foamed type concrete, no fines, and lightweight natural and artificial aggregates concrete. Natural LWA are normally obtained from the volcanic rocks such as pumice with density ranges from 500 kg/m^3 to 900 kg/m^3. Artificially manufactured LWA from various natural materials such as expanded clay, expanded shale, foamed slag, blast furnace slag, pulverized fuel ash and perlite to enable LWC and to achieve compressive strength up to 100 N/mm^2 [4]. In countries where copious agricultural and industrial wastes are discharged, can also be used as possible material in the concrete production. Literature show that, attempt has been made to use agriculture waste namely oil palm shell (OPS) as coarse aggregate in LWC [5].

Coconut shell (CS), one of the agricultural wastes, produced in abundance and has the potential to be used as coarse aggregate in concrete. Utilization of coconut shell as aggregate to get LWC is a relatively new field of research in concrete production. Concrete with CS as coarse aggregate can be used for the construction of pavements, blocks and pre-cast structural elements, low cost houses and farm structures etc,. This study is reviewed and identifies a sustainable affordable alternative to replace conventional coarse aggregate by CS as aggregates.

2. AVAILABILITY OF CS

Coconut is a versatile crop grown all over the world except the continents of Europe and Australia. Coconut is grown in more than 93 countries in the world. South East Asia is regarded as the origin of coconut. The total world coconut area was estimated approximately 12 million ha and around 93 percent is found in the Asian and Pacific region. The average annual production of coconut was estimated to be 54 billion nuts, or 10 million metric tons of copra equivalents. Of the world production of coconut, more than 50 percent is processed into copra. The main coconut players in the global market for 2005 are shown in Table 1. Eight of the ten largest producers are in the Asia Pacific region. The three main producers, Indonesia, the Philippines and India account for 75 per cent of world production [6]. According to Food and Agriculture Organization, FAO Statistics, 2007, global production of coconuts is 61504133 Tonnes with Indonesia, Philippines, India, Brazil and SriLanka as the major contributors to coconut production.

Table 1 Selected coconut production statistics, 2005

Country	Production(nuts)		Area	
	kt	***%***	***ha***	***%***
Indonesia	16 300	30.1	2670	25.0
Philippines	14797	27.3	3243	30.4
India	9 500	17.5	1860	17.4
Brazil	3 034	5.6	281	2.6
Thailand	1 500	2.8	343	3.2
Vietnam	972	1.8	110	1.0
Mexico	950	1.8	150	1.4
Sri Lanka	890	1.6	395	3.7
Papua New Guinea	650	1.2	180	1.7
Malaysia	642	1.2	179	1.7

India is one of the leading coconut producing countries in the world and the third largest coconut producing country, with an area of 1.94 million ha and annual production of 2.74 million tonnes copra equivalent; in that approximately 90% of total production of coconut is concentrated in South India [6]. Annual production is about 7562 million nuts with an average of 5295 nuts per hectare. Statistical data of coconut production shows that, India

accounts for over a quarter of the world's total coconut oil output and is set to grow further with the global increase in demand [7]. As per the recent Government of India statistics 2008-09, India has emerged as the largest producer of coconut in the world with a production of 15,840 million nuts. India accounts for 26.9 per cent of the world's production. In India, the four south Indian states namely Kerala, Tamil Nadu, Karnataka and Andhra Pradesh account for around 90 per cent of the coconut production in the country [8]. A sample coconut shell mound as wastes at some of the oil mills are shown in Fig.1.

Figure 1 Coconut shell mound as waste at some oil mills

CS represents more than 60% of the domestic waste volume (www.nmce.com/commoditystudy/ coconut_study.jsp) and presents serious disposal problems for local environment. The coconut shell as a waste from oil industry in India is approximately 8.16 million tones [9]. After the coconut is scraped out, the shell is usually discarded as waste. This CS is crushed and used as a coarse aggregate in the production of LWC. Coconut Shell Concrete (CSC) could be used in rural areas and places where coconut is copious and may also be used where the conventional aggregates are costly [10]. It has the dual advantage of diminution in the cost of construction material and also as a way of clearance of wastes [7].

3. PROPERTIES OF COCONUT SHELL

3.1. Use of CS for Different Purposes

CS is organic in nature. Since, CS has good durability characteristics, high toughness and abrasion resistant properties; it is suitable for long standing use. Because of its inherent characteristics of withstanding at high temperature, low burning and being floppy, it is widely used to manufacture insect / mosquito repellent coil, mouldings, bakelite powder, abrasives, plywood, mica, foundry chemicals, agarbathis, incense sticks and also find its use in plastic industries. It is also used as a raw material for activated carbon industries. It is used as filler for synthetic resin glues. It is used successfully with specialized surface finishing liquid products (as an absorbent), mastic adhesives, resin casting and bituminous products. It is used in heavy duty hand cleaner pastes as a mild abrasive. It is used as a lost circulation material in oil well drilling. Also, it is used as a mild abrasive in shot blasting of delicate objects and of historic buildings. In Asia, it is widely used for the manufacture of insect repellent in the form of mosquito coils and also in agarbathis, due to its long and uniform burning qualities. The product finds extensive use in plywood and laminated boards as a phenolic extruder and as filler in synthetic resin glues. Also, shell charcoal, shell based activated carbon, shell powder, shell handicrafts, shell ice cream cups and beer glasses, ladles, forks, show pieces, shell buttons, etc. are the coconut shell based products available [8]. Some of coconut shell products are shown in Fig.2. refered from google images, retrieved on 19.09.2016 at 10.30 pm.

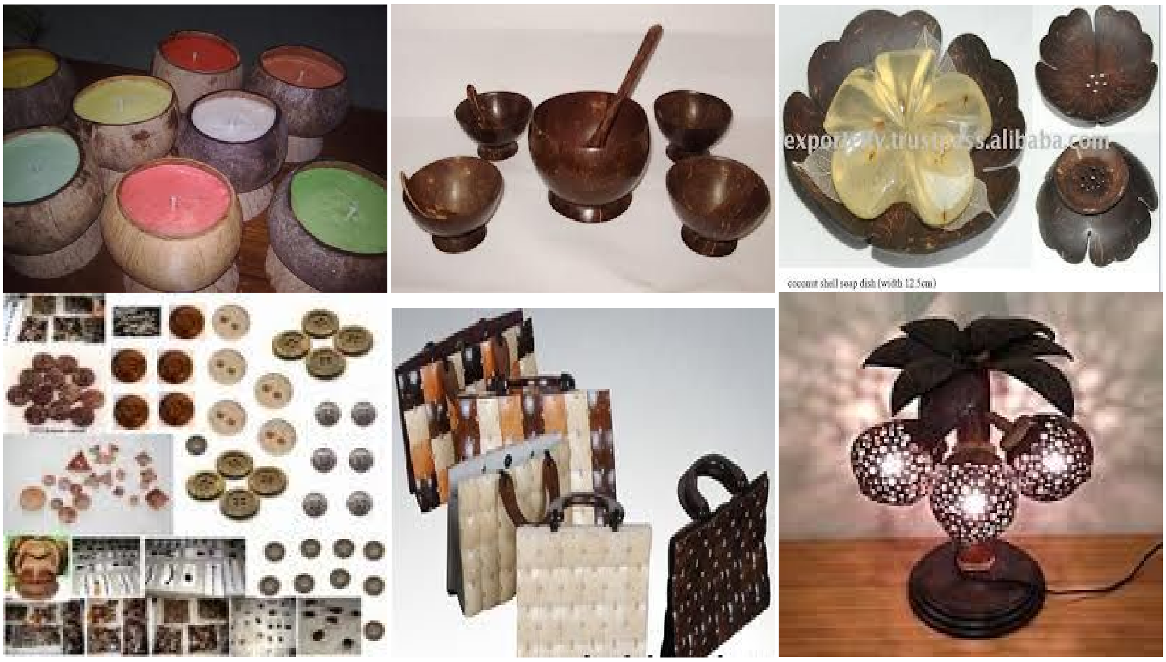

Figure 2 Coconut shell products: candles, ice cream bowls, soap dish, buttons, bags and lamps

3.2. Physical and Mechanical Properties of CS

The average moisture content and water absorption of the CS was 04.20 % and 24.00 % respectively. The average specific gravity and the apparent specific gravity were found as 1.05 to 1.20 and 1.40 to 1.50 respectively, which is far less than the conventional aggregates. This may be the reason for that, when CS is used in concrete it fall in the category of LWC. The average crushing value and impact value of the coconut shells are 2.58% and 8.15 % respectively, hence, CS can offer better resistance against crushing and impact. The average percentage loss in abrasion test on the coconut shells is 1.628 %., hence, CS can also offer more resistance against abrasion, compared to conventional aggregate. The average bulk densities in loose and compacted conditions are in the ranges of 550 kg /m^3 and 650 kg /m^3 respectively. Hence, CS aggregates result in less unit weight of concrete compared to normal weight aggregate and produces LWC [9].

3.3. Microstructure of CS

CS specimens have very closely spaced discrete cells having sizes between 16.36 μm and 29.33 μm and within the cells, it has micro-pores with sizes varying from 760.6 nm to 1.64 μm. Similarly, CS specimens also have some long continuous chain linked cells with different widths varying 7.35–8.88 μm. The thickness of continuous cells in the direction of widths varies in the range of 852.7 nm– 1.24 μm. These discrete and continuous chain linked cells of CS specimens could be the reason for resisting more impact, crushing and abrasion resistance of CS specimens. Water absorbed by the CS during soaking is stored and the pore structures inside the CS behave like a reservoir [7]. Microstructure of coconut shell is shown in Fig.3 [7].

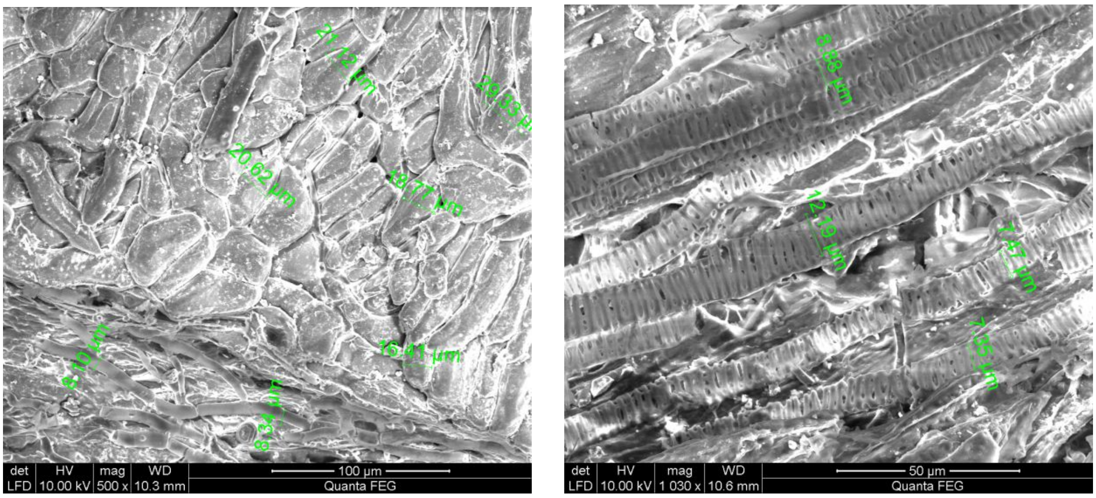

Figure 3 Microstructure of CS specimens: Discrete cells and continuous cells

3.4. Chemical Properties of CS

Since, concrete is an alkaline material that are readily attacked by acid, especially when the values of pH below 6.5. If sugar is present in the ingredients of concrete, virtually prevent the setting of cement. The sugar present in wood is the most critical compounds causing incompatibility between wood and cement. Sugar has a strong retarding effect on the setting and hardening of concrete. In severe cases of contamination with sugar, the resulting concrete may not set or may fail to gain appreciable strength. But, dry sugar has no effect on hardened concrete. Along with the sugar, the main saccharine of wood are cellulose, glucose, fructose, sucrose, etc. Other soluble materials may have insignificant influences on the hydration of cement. However, sugar present in CS is not going to come out and react with other ingredients of concrete, to alter the setting action. Therefore, there is no need to treat the CS before use as an aggregate [9].

3.5. Coconut Shell – Cement Compatibility

Coconut shell fines required more water to obtain same consistency compared with neat cement. This may be due to the high water absorption of the coconut shell fines. The setting of CS fines-cement composite is delayed, it is probably due to the presence of botanical components and some water soluble sugars in CS that inhibit the setting and hardening of cement**.** If the final setting time is less than or equal to 15 h, it is suitable for aggregate/cement compatibility. The coconut shell-cement composites are compatible. It is suggested that there is no pre-treatment is required for coconut shell fine- cement composites. The required compressive strength can be achieved by adding more quantity of cement compared with neat cement composites. It is probably due to the relatively low density of the coconut shell particles. The maximum hydration temperature of neat cement and coconut shell fine cement composites is observed 73°C and 63°C respectively. It is suggested that the maximum hydration temperature is greater than 60°C, is considered suitable for aggregate / cement compatibility. The maximum hydration temperatures values observed are greater than 60°C and hence, it is compatible [6].

4. COCONUT SHELL CONCRETE (CSC)

4.1. Cement Content and Wood –Cement Ratio

At 28-days, minimum compressive strength should be greater than 17 N/mm^2 to satisfy the criteria of structural LWC as per ASTM C 330. Therefore, it is recommended that the cement content to be used in the range between 480 to 510 kg/m^3 for CSC to meet this minimum requirement. A wood–cement ratio of 0.65 may be taken as optimum for CS aggregate to satisfy the criteria of structural LWC strength as per ASTM C 330 [10].

4.2. Workability and Density

Because of the smooth surface on one side of CS and the size crushed CS, CSC has better workability and also has 28-days air-dry densities less than 2000 kg/m^3 for the typical trial mixes of CSC [10].

5. MECHANICAL PROPERTIES OF CSC

5.1. Compressive Strength

Strength of the cement matrix and the particle tensile strength of the aggregate are the facts which affect the compressive strength of concrete. It is usually related to the cement content, required workability and air content, rather than water-cement ratio. Since it is somewhat difficult to determine that, how much of the total mix water is absorbed by the aggregate and thus how much water is available for the hydration processes. Therefore, while producing CSC, CS coarse aggregates are to be used in saturated surface dry (SSD) condition and the water–cement ratio is to be optimized to obtain desired workability. During compression test, breakage of the CS aggregate indicates that the individual shell strength had a strong influence on the resultant concrete strength [10].

5.2. Effects of Curing Conditions on Compressive Strength

Intermittent curing (site curing) conditions produced the highest CSC strength, followed by full water curing, and then air-dry curing. Since, water is continuously available in case of full warer curing, and thus creates lubrication between CS and the cement paste and may also have reduced the heat of hydration. But, in the case of intermittent curing, water is not available throughout its curing period. The absorbed water from the CS pore structure reservoir would help for continuous hydration process at the time of lack of water. Therefore, there is no chance of lubrication development between the CS and the cement paste. In the case of air-dry curing, because of no water supply, for hydratioin process the water absorbed by CS during the time of soaking help to some extent. Development of compressive strength takes place in the early stages and continues to increase over the period of age. Even after 365-days of age, CSC gaining the strength and also biological decay was not evident indicated that the CSC does not deteriorated once CS aggregates are encapsulate into the concrete matrix [7].

5.3. Ultrasonic Pulse Velocity (UPV)

It was reported that the CSC can be graded as good. In this parameter study also higher pulse velocities were obtained under intermittent curing compared with full water curing and air-dry curing. There was an improvement on the pulse velocity and no significant drop under all types curing like full water curing, intermittent curing and air-dry curing conditions at an age of 90-days. There is an uniformity and no defect is CSC; because there are not much differences in pulse velocities tests in those three curing conditions [7].

5.4. Flexural and Splitting Tensile Strength of CSC

Flexural strength is usually 10–15% of compressive strength in conventional concretes. In CSC, flexural strength are higher than the conventional concretes and emphasized the statement that the behavior of CSC is similar to that of conventional concrete. Tension failures occur by breaking the matrix bond and surface of the aggregates or by concrete matrix fracture in conventional concrete. Unlike the conventional aggregates, CS is likely to fracture but it was not happened in CS when it is used as aggregate in CSC. Therefore, the brittle nature of CS is not a constraint to use as an aggregate in concrete production. Also, because of the reduction of sizes of CS, its fracture ability may also probably decreases. It was stated that the behavior of CSC under flexural tests and split tensile strength tests are similar to that of conventional concrete [10].

5.5. Impact Resistance of CSC

If the strength of concrete increases, impact resistance of concrete specimen increases generally both for initial cracks and failure cracks. But there is an optimum value, more than that there is a reduction of impact resistance both at first and final failure cracks while the strength of the concrete increases. Impact résistance of CSC is 32 blows in which compressive strength of CSC was 26.70 N/mm^2 which was nearly 50 % more compared with the 22 blows of normal aggregate concrete which had compressive strength of around 45 N/mm^2. This enhancement of impact resistance of CSC is due to the fibrous nature of CS aggregates [10].

5.6. Bond Strength of CSC

The bond strength of CSC specimens with plain bars ranged from 15 to 32% and deformed bars ranged from 18 to 42% of compressive strength of the CSC. Its bond strength is comparable to the conventional concrete and other LWC generally. Failure of bond took by pulling the plain bars out of the concrete and failed by forming concrete cover cracks on deformed bars bond tests. Bond strength decreases when the bar size increases for both plain and deformed bars [10].

5.7. Curing Conditions Effect on Bond Strength of CSC

Development of bond strength took place in early ages for most of the specimens. Bond strength increases significantly up to the age of 56-days under full water, intermittent and air-dry curing conditions. Thereafter, the development of bond strength was gradual and almost constant. In this case also, intermittent curing condition produces the highest bond strength followed by full water and air-dried curing. The reason is the same as explained for compressive strength in the section 5.2 above [7].

5.8. Development of Bond between CS Aggregate and Cement Paste

It is reported that the fissure gap between the CS aggregate and the cement paste was approximately 52.31–88.27 µm, 41.72–47.96 µm, and 24.94–26.63 µm at 3 days, 7 days, and 28 days respectively. From this it was reported and concluded that the fissure zone between the CS and the cement paste was getting narrow due to age of concrete. Therefore, there was the development of bonding between CS aggregate and cement paste [7]. Fig.4 shows the bond development between cement paste and CS in CSC at 3, 7, and 28 days respectively [7].

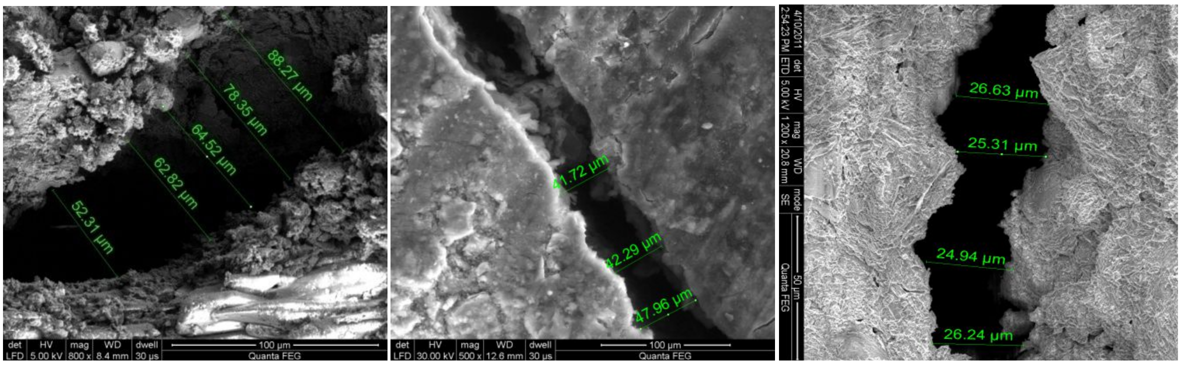

Figure 4 Bond developed between cement paste and CS in CSC due to age (3,7 and 28 days)

6. STRUCTURAL ELEMENT BEHAVIOR OF CSC

6.1. CSC Beams under Flexure

Under flexural tests, CSC beams behavior was also in traditionally structural in parallel to conventional concrete. It was reported that, bond failure was not occurred between the reinforcement and CSC. Experimental ultimate moments were 09–45% higher than the theoretical moments for CSC beams when reinforcements ratio of 3.14% or less. For reinforcement ratios higher than 3.89%, it was about only 5% higher. For the estimation of ultimate moment of CSC beams, both BS 8110 and IS 456 can also be used. Under service loads, defelctions of CSC beams were within the limits allowable as per the standards. Because of the nature of good shock absorbance potentials of CS aggregates, CSC beams under flexure shows relatively good ductility. Crcak widths developed in CSC beams under flexural tests in service loads were within the limits specified by the standards. CSC beams able to attain strain capacity fully under flexure. Just prior to failure of CSC beams under flexure, the developed end rotations were comparable to other LWC [11].

6.2. CSC Beams under Shear

Under shear tests also, CSC beams behavior were also in traditionally structural in parallel to conventional concrete. When CSC beams not provided with shear reinforcement and tested, diagonal tension failure were occurred. Flexural mode of failure was noticed in CSC beams when provided with shear reinforcement. CSC beams tested under shear suggested that there is strong bonding exist between the reinforcement and CSC as it is happening traditionally in conventional concrete. There is proper justification for the occurrence of good interlocking of CS aggregates in CSC from the pattern of initiation of cracks and its propagations to the final positions. Large anchorage stresses was developed in the support zone, however no horizontal splitting of concrete was found both in shear and flexural zones. Deflections developed in CSC beams were greater than the conventional beams both with and without shear reinforcement cases due to low modulus of elasticity of CSC compared to conventional concrete. However, at service loads the defalcations were within the allowed limits. Because of due to good CS aggregate interlocking, experimental results higher than the predicted value as per the standard. Compared to conventional concrete beams, shear and flexural cracks appeared twice in CSC beams. Until the formation of cracks in concrete, there was a linear relationship in tensile and compressive strains in CSC beams of with and without shear links. Once the cracks formed, strains in steel increase in a steady manner until yielding. Before the main reinforcement fails, higher strains happened in shear links. Both in the cases of with and without shear links in CSC beams, higher concrete compressive strains measured

prior to failure compared to conventional concrete beams. This shows that there was strong bonding between the CS aggregates and the reinforcements [12].

6.3. CSC Beams under Torsion

Initially cracks developed on the wider face of the CSC beam, propagated suddenly to the entire depth then formed in shorter face of the beam before the beam fails. Spiral cracks were developed approximately at 45° and extended over the test area of the CSC beam. It was reported that the applied torsion was resisted by the concrete up to the formation of cracks and CSC beams behaves elastically, since the torque versus twists obtained was linear and hence it was confirmed. CS aggregates have less stiffness comparatively with conventional aggregates and because of this, cracking occurs in CSC beams earlier than the conventional concrete beams. To calculate the theoretical crack strength under torsion, equation suggested by Macgregor is more conservative compared to ACI prediction [13].

After the formation of cracks, torque versus twists reported as non-linear. Due to the fibrous nature of CS, ultimate torque strength resistance of CSC beams were high compared to conventional concrete beams and it was quite interesting. To calculate the ultimate strength under torsion, ACI prediction is more conservative compared to equation suggested by Macgregor [13]. Compared to ACI and Macgregor equations, Indian Standard is also conservative, however it was under estimated. In ductility parameter study, CSC beams have similarity behviour compared to conventional concrete beams. Again from this also, it was stressed that, due to the fiberous nature of CS aggregates, ductility was more in CSC beams. Because of less stiffness of CS aggregates, crack widths were slightly on higher side compared to conventional concrete beams crack widths. To calculate the theoretical stiffness, equation suggested by Park and Paulay is conservative [13].

6.4. Shrinkage Study on CSC Slabs

Both density and compressive strength of CSC are inversely proportional to percentage of CS aggregates used in the production of CSC. Similarly, plastic shrinkage characteristics of CSC also inverse with the addition of percentage of CS aggregates and plays an important role on the property of shrinkage of concrete [14].

6.5. Deflection Study on CSC Slabs

Central deflection of CSC slabs is directly proportional to percentage of CS aggregates used. CS aggregates exhibits and plays an important role for the enhancement of ductility property of concrete, because CSC slabs under test gave warning time more before it fails compared to conventional concrete [14].

6.6. Stress-Strain Characteristic of CSC

For conventional concrete as per IS 456: 2000 the ratio of cylinder to cube strength is approximately 0.8, but it was slightly less in CSC. Similarly, stress-strain curve obtained for CSC was not conservative in parallel with IS 456:200 which is applicable for conventional concrete. Static modulus of elasticity of CSC is concurrent with oil palm shell concrete. This value was varied from 6.9 to 7.5 GPa. CSC beams attained the similar pattern of parabolic stress-strain curve of conventional concrete, but the strain value of CSC was higher. At failure of CSC beams, ultimate strain of CSC was found as 0.006 and this value is approximately twice as that of conventional concrete. Compared to over reinforced CSC beams, under reinforced CSC beams had less moment capacity and vice versa in the study of deflection due to the yield of tension steel. CSC beams final failure strains results in ductile failure and the ductility ratio of CSC beams ranged from 2.68 to 4.9 and these values

conservative with oil palm shell concrete beams. In CSC beams, at serviceable loading conditions, crack width developed is within the allowable limits specified by codes and standards [15]. Fig. 5 shows the cross sectional view CSC cylinder specimen.

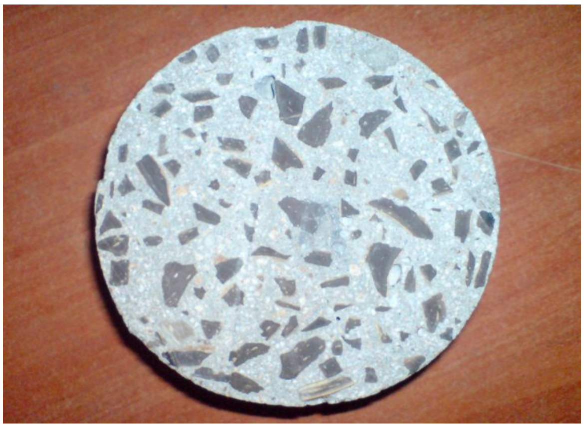

Figure 5 Cross sectional view of CSC

7. DURABILITY PROPERTIES OF CSC

It was reported that the CSC specimen water absorption and permeable pore voids were decreases as the age of curing increases under full water, intermittent and air-dry curing conditions employed. At early age of curing, water absorption of CSC specimen does not show any significant effect due to different state of curing conditions. Since CS has the capacity to absorb water and retain in its as a reservoir which helps for internal curing was the possible reason for the above. However, there were significant differences happened at later ages. Therefore to overcome this, there is a need of proper curing whenever CS is used as aggregate in concrete production. Sorptivity values of CSC were comparatively well with those of other LWC prepared from expanded shale and sintered pulverized fuel ash, and oil palm shell. Rapid chloride penetration test indicated that the CSC specimen shown moderate chloride-ion penetrability. Due to the porous nature of CS, surface chloride concentration on CSC specimen were quite high. However, chloride content decereases towards depth inside the CSC specimen from the surface. CSC specimen tested under elevated temperature results showed that the resistance, change of colours and the residual strength of CSC specimen were comparatively well with other LWCs reasonably [16].

8. PRACTICAL IMPLEMENTATION OF CSC

To show the use of CSC in practice and to made the awareness about this established CSC, some of the non-structural elements like hollow blocks, joinery items were produced with CSC and also a precast reinforced CSC slab was cast using layman methodology without any technical force during the year 2007 in the University premise. This precast CSC slab was constructed with the supports of CSC hollow blocks and the slab being allowed to bear some practical loading till today. Till today, that CSC slab performing well without any difficult experience technically. Therefore, from the review of literatures on CS and CSC and also this example of using CSC in practice gives confident that the CSC is one of the potentially developed special concrete and CS become one of the fine alternate for convenetional aggregate in the near future. Fig. 6 shows some of the elements made use of CSC for practical implementation.

Figure 6 CSC hollow blocks, Jallies, and slab under service

9. CONCLUSION

Due to the depletion of natural resources of conventional aggregates, researchers are searching for sustainable development of the alternative aggregates is one of the prime of importance in concrete production and construction industries as well. One of the research area taken by many researchers is an attempt to replace the conventional aggregate by coconut shell and all of them have succeeded in their research and found encouraged and positive results to use CS as one of the promised material as an aggregate in concrete production.

From the review of literatures surveyed on coconut shell concrete, it can be concluded that the coconut shell is one of the agricultural wastes, produced in abundance and has the potential to be used as coarse aggregate in concrete. Indonesia, Philippines, India, Brazil and SriLanka are the major contributors to coconut production. Coconut shells are widely used to manufacture insect / mosquito repellent coil, mouldings, bakelite powder, abrasives, plywood, mica, foundry chemicals, and agarbathis, incense sticks and also find its use in plastic industries. Use of coconut shell in concrete has the dual advantage of diminution in the cost of construction material and also as a way of clearance of wastes. Also, shell charcoal, shell based activated carbon, shell powder, shell handicrafts, shell ice cream cups and beer glasses, ladles, forks, show pieces, shell buttons, etc. are the coconut shell based products available.

CS aggregates result in less unit weight of concrete compared to normal weight aggregate and produces LWC. No need to treat the CS before use as an aggregate in concrete production except for its water absorption characteristics. The coconut shell-cement composites are compatible. It is recommended that the cement content to be used in the range between 480 to 510 kg/m^3 for CSC to meet this minimum requirement. A wood–cement ratio of 0.65 may be taken as optimum for CS aggregate to satisfy the criteria of structural LWC strength as per ASTM C 330. Even after 365-days of age, CSC gaining the strength and also biological decay was not evident indicated that the CSC does not deteriorated once CS aggregates are encapsulate into the concrete matrix. There is an uniformity and no defect is CSC. Behavior of CSC under flexural tests and split tensile strength tests are similar to that of conventional concrete. There was enhancement of impact resistance of CSC due to the fibrous nature of CS aggregates. Bond strength of CSC were comparable to that of conventional concrete and other LWC. Structural element behavior of CSC beams under flexure, shear and torsion were comparable with conventional concrete and also with other LWCs. CS aggregates plays an important role on the property of shrinkage of CSC. CSC slabs under test gave warning time more before it fails compared to conventional concrete. Durability tests on CSC specimen were given encouraged results to use CS as an alternate aggregate in the concrete production. Practically applied CSC elements under service for the

past ten years of service proved that the coconut shell become one of the best alternatives for normal coarse aggregate.

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